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The Structure And Magnetic Properties Of $Fe_{0.50}Cr_{0.50-X}Si_X$ (X=0-0.1) Nano Materials Prepared Via Mechanical Alloying Technique

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Abstract – The main objective of this study is the investigation of the relationship between the structure and the magnetic properties of $Fe_{50}Cr_{50-x}Si_x$ (x=0-0.1) metastable alloys which were made by mechanical alloying for 36 hours. Research in this field feels still lacking. To understand the structure using by X-ray diffraction (XRD) and the magnetic properties are measured by using a Physical Property Measurement System (PPMS). The result with variable of x = 0-, 0.025-, 0.050-, 0.075- and 0.1 wt. %. are crystallite sizes (D) increase from 7 to 8.5 nm, the structural strains (ϵ) are down about 20% from normal circumstances. The grain sizes increase causing the number of domains to increase then the mobility of domain decreases or coercivity (Hc) decreases from 120 to 40 Oe. In amorphous state coercivity rises and crystallite sizes decrease, suddenly.

Keywords – $Fe_{0.50}Cr_{1-0.50}Si_x$ nanocrystalline and amorphous alloys, structural and magnetic properties.

I. INTRODUCTION

Nanocrystalline and amorphous magnetic materials have been studied for many applications in industrial products, including transformers, motors, and a wide variety of magnetic components in sensors, power electronics, electrical energy control/management systems, telecommunication equipment and pulse power devices [1-2]. These alloys have superior corrosion and crack resistance [3], and resistance oxidation so high [4] making them candidate materials for several engineering applications such as accident-tolerant fuel cladding.

The nanocrystalline supersaturated solid solutions and amorphous phase in the powders are obtained during mechanical alloying [5-6]. Nanocrystalline materials obtained by high-energy ball milling are of great interest since it is known that those materials may exhibit different electrical, magnetic, optical, and other physical properties in the nano-regime due to finite size effects [7].

Mechanical alloying (MA) is a non-equilibrium solid-state alloying technology for powders and can be used to synthesize novel alloys impossibly obtained by conventional technology. It is well known that mechanical alloying of elemental metal mixtures can generate equilibrium and non-equilibrium structures, including supersaturated solid solution, nanocrystalline, metastable compounds and amorphous solids [8-9].

Nanocrystalline magnetic materials are intensively investigated because of their remarkable properties such as coercivity and saturation magnetization, which significantly differ from those of microcrystalline materials and are sensitive to the structure and microstructure. It is known that the interplay between the crystallite size and the magnetic properties i.e. saturation magnetization, coercivity of FeCr and FeCrSi alloys with nanometer crystallite size is not yet understood fully.

Although important progress has been made in the study of nanocrystalline magnetic materials prepared by mechanical alloying methods, there are numbers of open questions, whose solution could help to advance both their theory and practical

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applications. Among the challenges facing experts are those concerned with the correlation between *structural and magnetic properties* of materials at nanocrystallite size scales.

The formation of the disordered bcc Fe(Si,Cr) solid solution. After 15 h of milling, the coercivity and magnetization values are 81.7 Oe and 120.3 emu/g, respectively [10].

The transition metal-metalloid (TM-M) alloys are an important class of magnetic amorphous alloys. The transition metal component is usually about 80 percent of Fe, Co, or Ni, with the metalloid component B, C, Si, P, or Al. The presence of the metalloids lowers the melting point, making it possible to quench the alloy through the glass transition temperature rapidly enough to stabilize the amorphous phase [11]. In 36 h milling alloys, we still found magnetic saturation [12].

In previous studies authors have found some nano crystalline alloy via MA technique, combining elements such as Fe - Mn, Fe - Al, Ni - Al - C and Fe - Mn - Al [13-16].

II. Experimental

The $Fe_{0.50}Cr_{1-x}Si_x$ (x=0, 0.025, 0.05, 0.075, and 0.1 wt. %) nanocrystalline alloy and amorphous samples were prepared by mechanical alloying using a FRITSCH mixer with stainless-steel balls and a stainless-steel vial with comparition of 1:6. The starting mixture of $Fe_{0.50}Cr_{1-x}Si_x$ will perform by using commercial powders. This process will be performed in an Ar ambient to avoid oxidation.

The starting mixture of $Fe_{50}Cr_{50-x}Si_x$ alloys was formed using commercial powders of Fe (53 µm, 99.9%), Cr (75 µm, 99 %) and Si (105 µm, 99 %). For the purpose of milling, the weingh ratio of the ball to powder was 6:1. $Fe_{50}Cr_{50-x}Si_x$ alloy were mixed and grounded for same time, 36 hrs. The process was performed in an Ar gas ambient to avoid oxidation.

After the preparation, structures are carried out using an X-ray diffractometer with the Cu-Ka radiation. The data were analyzed using Materials Data Inc (MDI) software and got intensity. Based on these data, the grain sizes and the strain of the samples were estimated in terms of the William Hall method. Then, magnetic properties were carried out using Physical Property Measurement System (PPMS) from Quantum Design.

III. Results and Discussion

Fig. 1 shows the X-ray differaction (XRD) of the $Fe_{0.50}Cr_{0.50-x}Si_x$ (x=0, 0.025, 0.050, 0.075, and 0.100) and unmilled of pures Fe, Cr, and Si materials. All samples were milled of 36 hours. The XRD pattern of the unmilled samples indicates the characteristic reflection of individual constituent of the Fe, Cr, and Si elements. After milling, there are appeared bcc phease (A2 solid solution α-Cr (Si, Fe) and amorphous in x=0.1. In A2 phase, Fe and Si atoms were dissolved into the Cr lattice.

Fig. 2 shows all the the $Fe_{0.50}Cr_{0.50-x}Si_x$ (x=0, 0.025, 0.050, and 0.075 wt. %) peaks are broader and shifted to bigger angles, which is due to the structure deformation. The deformation is due to the replacement Cr atoms by Fe and Si atoms as defects caused by large local strains in the samples, which is a signal for the formation of an alloy. One can also see that all peaks have the same trand belonging to the bcc phase structure. Futhermore, the peak positions shift slightly towerd bigger angle upon partial substitution of Fe and Si for Cr-site, indicating decreases in lattice parameter based on Bragg law. In Si = 0.10 wt. % the sample have been amorphouse, the Bragg's law no longer applies.

The crystallite size and the strain based on Cr (110) peaks as a function of Si variable, for the $Fe_{0.50}Cr_{0.50-x}Si_x$ (x=0, 0.025, 0.050, and 0.075) system is shown in **Fig. 3.** Based on the XRD data the crystallite sizes be evaluated from the Scherrer formula, $D = 0.89\lambda/(B\cos\theta_B)$, where λ is the X-ray wavelength (1.5406 Å), θ_B the diffraction angle at the peak, B the full width at half maximum (FWHM). The crystallite sizes of the samples rose from 7-8.5 nm following the increase

in quantity of Si. Lattice strains are calculated based on the Willianson-Hall plot:B cos θ = (Kλ/D) + 2ϵ sin θ, where B is the full width at half maximum (FWHM) in radians, D is the average crystallite sizes, ϵ is the strain, K is the shape factor, λ is the X-ray wavelength and θ is the Bragg angle. The structural strains (ϵ) are down about 20% from normal circumstances.

In **Fig. 4**, the distance between atomic layers and lattice parameter in a crystal plan hklcan be evaluated from Bragg condition, $\lambda = 2d_{hkl}\sin\theta$, where d_{hkl} is the distance between atomic layers in a crystal plan hkl. In this case, $d_{hkl} = a/(h^2 + k^2 + l^2)^{1/2}$. As a result of the approximate distance between the atomic layer d and lattice parameter a_0, it decreased with the increase of Si fraction from 2,034 to 2,020 A and 2,876 to 2,858 A.

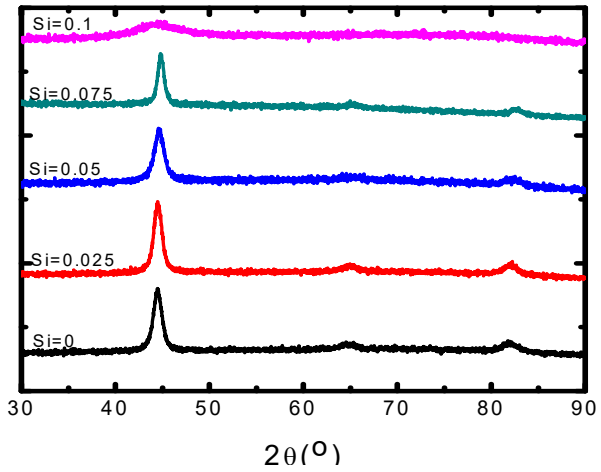

Fig. 1: XRD of $Fe_{0.50}Cr_{0.50-x}Si_x$ (x=0-0.1 wt. %) milled all samples of 36 hours and unmilled of pures Fe, Cr, and Si.

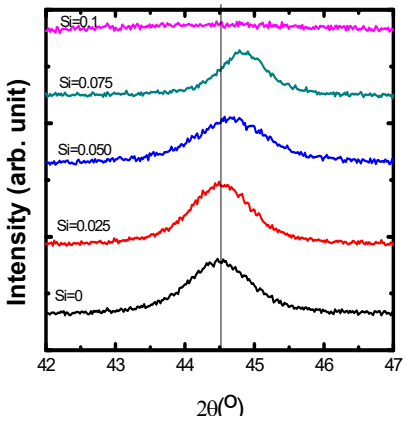

Fig. 2: XRD of $Fe_{0.50}Cr_{0.50-x}Si_x$ (x=0-0.1 wt. %) patterns are broader and shifted to bigger angles due to the structure deformation.

In **Fig. 5** displayed variations of silicon content hysteresis loops. Magnetization is reduced if the Si fraction (diamagetic) increased, at x_{Si}= 0.1 wt % magnetization is almost zero, seen also in Fig. 6. If we compare Fig. 3 and 6, crystallite sizes (D) increase from 7 to 8.5 nm then grain sizes increase causing the number of domains to increase then the mobility of domain decreases or coercivity (Hc) decreases from 120 to 40 Oe. In amorphous state coercivity rises and crystallite sizes decrease, suddenly.

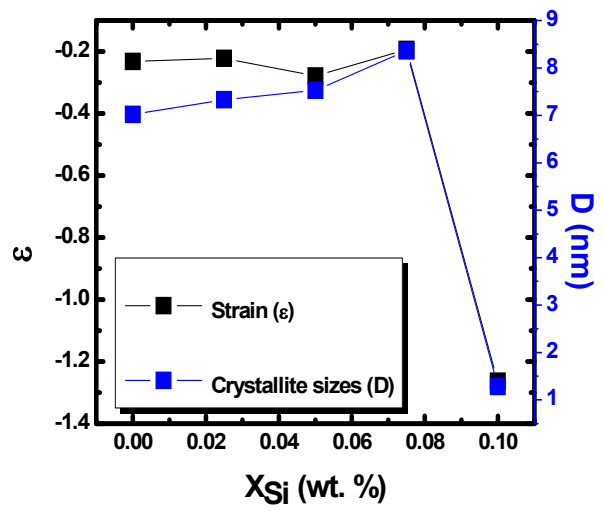

Fig. 3: The strain and crystallite sizes based on Cr (110) respect to Si content for the $Fe_{0.50}Cr_{0.50-x}Si_x$ (x=0, 0.025, 0.050, and 0.075 wt. %) system.

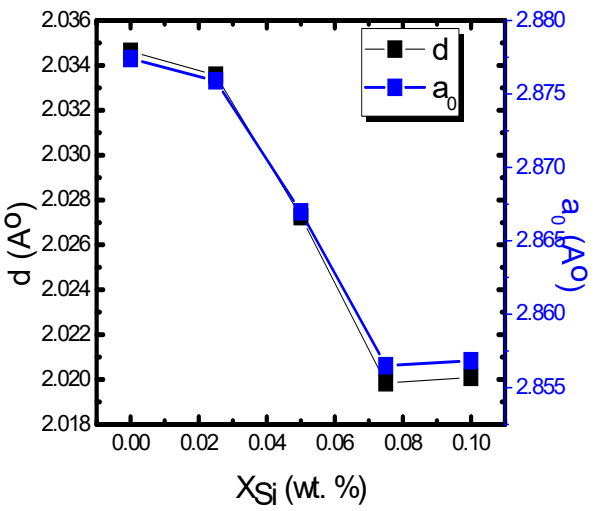

Fig. 4: The d spacing and lattice parameter based on Cr (110) respect to Si content for the $Fe_{0.50}Cr_{0.50-x}Si_x$ (x=0, 0.025, 0.050, and 0.075 wt. %) system.

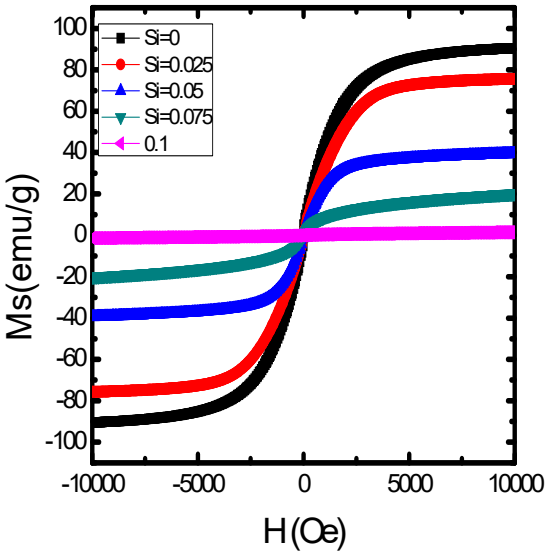

Fig. 5: Hysteresis loop a variation of Silicone content.

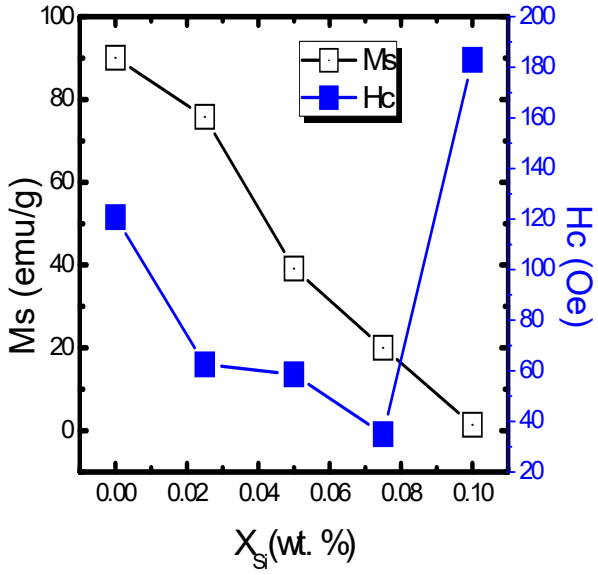

Fig. 6: The magnetization and coercivity versus a variation of Silicone content.

IV. Conclusion

Based on the results, we can conclude the $Fe_{50}Cr_{50-x}Si_x$ (x = 0-, 0.025-, 0.050-, and 0.075 wt. %.) samples that produced by mechanical alloying present ferromagnetic crystals but in x= 0.1 wt. % the sample have been amorphouse. We suggest that the crystal structures are bcc type and the elements Cr replace by the Fe and Si atoms, as explicitly shown by the XRD peaks of $Fe_{50}Cr_{50-x}Si_x$.(x=0-0.1). The grain sizes increase causing the number of domains to increase then the mobility of domain

decreases or coercivity (Hc) decreases from 120 to 40 Oe. In amorphous state coercivity rises and crystallite sizes decrease, suddenly.

V. ACKNOWLEDGMENTS

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